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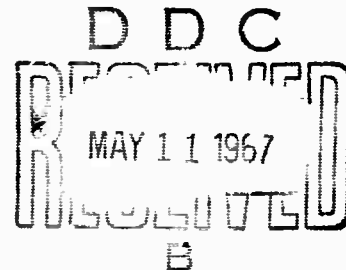
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CENTER FOR HIGH ENERGY FORMING

SEVENTH QUARTERLY REPORT  
OF TECHNICAL PROGRESS

G. A. Thurston

April 1, 1967



U. S. Army Materials Research Agency  
Watertown, Massachusetts 02172

Martin Marietta Corporation  
Denver Division  
Contract DA 19-066-AMC-266(X)  
The University of Denver  
Denver, Colorado

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## ABSTRACT

Preliminary results have been obtained from a computer program that predicts strains in a circular blank forced into an ellipsoidal die. For the first time, the analysis accounts for flange pull-in directly. The program will provide useful information in selecting blank dimensions for specific applications and will reduce the amount of sub-scale testing required.

Stabilizing the edge of blanks by a chevron ring pattern engaging a welded rim has been shown to reduce the scatter in strain distribution for parts formed into a die. This is especially important for material that work-hardens during forming and for parts that must be chem-milled after forming.

Initial tests indicate that useful data can be read during explosive forming from strain gages attached to the blank even though the gages do not survive the entire forming process.

All single-shock aluminum specimens have been shock-hardened and selected multiple-shock tests are underway.

Displacement-time data for expanding ring strain-rate measurements are being differentiated using a least-squares computer subroutine.

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## I. MARTIN MARIETTA CORPORATION

### 1. Strains in a Deformed Blank in Contact with a Die

The computer program has produced convergent solutions in test cases. The preliminary results are very encouraging. For the first time, stresses and strains in the dome, fillet radius, and flange of a formed dome are matched in a continuous fashion in one computer operation without trial and error on the part of the user.

Figure 1 represents a die contour that was assumed for the first test case. The dome is a spherical cap attached to an exaggerated circular fillet tangent to the cap and flange. Figure 2 shows the strain distribution for a part formed into this die. The program uses simple deformation theory of plasticity with a true stress-strain curve of a Ramberg-Osgood type

$$\epsilon = \frac{\sigma}{E} \left[ 1 + A \left( \frac{\sigma}{\sigma_1} \right)^{n-1} \right] \quad (1)$$

In Eq. (1),  $\sigma$  and  $\epsilon$  are the stress and strain while the constants used in this particular test case are:

$$\begin{aligned} E &= 10 \times 10^6 \text{ psi, Young Modulus} \\ A &= .4, \text{ Constant Parameter} \\ n &= 4.0, \text{ Constant Parameter} \\ \sigma_1 &= 40 \times 10^3 \text{ psi, Yield Stress} \end{aligned}$$

A common practice in industry for estimating charge requirements for forming a spherical cap is to assume no pull-in and compute strain energy on the basis of a uniform strain equal to the percentage increase in arc length of the die compared to the initial length of the chord. In the test case, this true strain is approximately equal to 7.1 per cent. The computed strains allowing for pull-in are considerably less than this value, except near the apex, which means that the approximate charge estimation will be too high.

The strain data can be plotted in another manner to give additional useful information. The radius at any given point in the flange can be considered as the outside radius  $B/2$  of another blank. Then the radial displacement  $u$  computed in the flange at  $B/2$  is equal to the edge pull-in of a blank of diameter  $B$  that will produce the same strain distribution in the dome. The ordinate of the curve in Figure 3 is this pull-in in non-dimensional form with the abscissae the  $B/D$  ratio for different size blanks to produce domes of diameter  $D$  with the same strain-distribution.

Currently, the computer program is being modified to handle cases where the fillet radius is so small that it can be neglected. The analysis and additional results will be described in a paper at the First International Conference of the Center for High Energy Forming.

## 2. Blank Stabilization

Work continued on stabilizing blanks against uneven pull-in. The Sixth Quarterly Report contains pictures of a chevron ring pattern that is effective in controlling pull-in. The impact on the chevron as the ring closes damages hardened 4130 steel chevrons. Inserts of 1100 aluminum material placed in cut-outs in the chevron tip reduce the damage so that the chevrons can be used for many shots. Weld beads have proven most effective as rims to engage the chevron pattern. Crimping the edge of the circular blanks into a rolled section has shown promise and is cheaper than the welded bead.

A series of shots was made on two sets of three identical blanks. The first set had welded beads and chevrons to control pull-in. The second set relied on friction between the die and flange to control pull-in plus the stiffness of the blank rim which had a B/D ratio of 1.45.

Figures 4, 5, and 6 are plots of the scatter band of data for measured strain distributions along two diameters for the three parts formed into a die. The scatter band is narrower for the parts with controlled pull-in.

Figures 7 and 8 show the die contour and measured deviation from contour for two typical parts. The deviation from contour was greater for the parts with controlled pull-in. A contributing factor to this is some bending in the flange which lifted the dome away from the die. Trimming the edge of the flange would allow the dome to drop further into the die cavity and reduce some of this deviation uniformly.

The controlled pull-in made the part conform closer to the sharp fillet radius than the parts controlled by friction.

The abrupt fillet radius is the cause of the high radial strain that appears in the dome. The die is a sub-scale model of the die to form a dome that was previously manufactured by spinning. This insistence of the customer on retaining the sharp fillet is a minor example of a coupling problem in replacing one technology with another.

## 3. Results of Strain Gage Measurements

Work was initiated to measure strains in blanks during

forming. The gages which have shown the most promise are the High Elongation gages manufactured by Budd Instrument Company and the Post-yield gages produced by BLH. Both gages can measure static strains on the order of 15 per cent when used with special epoxy adhesives.

Preliminary tests show that the gages do not survive the forming operation. However, an oscilloscope trace showed strains of over 2 per cent in a test of one gage and it appears possible to read higher strains when the sweep rate of the trace is adjusted to give better time resolution.

Even if the strains that can be measured in this manner are only a fraction of the total strain, the time history for given gages and the time lag in response of gages at different locations on a blank will provide insight into the response of the blank to explosions.

## II. UNIVERSITY OF DENVER

### 1. Shock Hardening

During this period all of the single-shock aluminum specimens were subjected to shock hardening. Alloys include pure aluminum, 2219, 2024, 2014 and 7039 in both the precipitation hardened and annealed conditions. Tensile testing and metallography of these specimens is underway. The stacking fault probability study of 70-30 brass and pure copper is almost completed. Shock hardening studies on prestrained iron has been concluded and a phase report is being prepared. Low-pressure, multiple-shock tests are currently being conducted on selected aluminum alloys.

### 2. Strain Rate Experiments

Dynamic measurements of the displacement-time history of expanding ring specimens of 6061-T6 aluminum were continued. The problem of repeated impacts between the steel core and the aluminum ring was eliminated by the use of tapered steel core described in the last report. This geometry produces separation times on the order of 70 to 120 microseconds which is in excess of the actual time required for complete expansion of the ring within the range of strain rates of interest. Symmetrical expansion of the ring specimen can now be obtained quite easily with a high degree of reliability. Displacement-time data collected to date will be reduced using computer techniques to provide more consistent results. The computer program was written during this period and data analysis is presently underway.

### 3. High Strain Rate Ductility

An investigation is being conducted into the mechanism(s) which govern the increase in ductility which occurs for many FCC-matrix alloys as deformation rates are increased in the range of 50 to 1000 fps. A preliminary theoretical consideration of existing data led to the tentative conclusion that the ductility transition coincides with the onset of plastic stress wave propagation, i.e., nonuniform straining. Confirmation of this hypothesis is presently being sought by explosively forming aluminum strip of variable widths from 1/8 in. to the full 3-in. dome configuration. This permits an evaluation of the effect of deformation velocity on the maximum uniform strain and resulting metallurgical structure as a function of stress state and the constitutive relation. The latter, in turn, affect the point of onset of nonuniform deformation.

#### 4. Explosive Welding

Dr. Steve Carpenter spent two days at the Battelle Memorial Institute with Mr. R. J. Carlson reviewing the extensive explosive welding experience of this group. During this visit, attempts to reduce welding data to formulation were discussed and reviewed. As a result some changes have been made on the computer program being written by Dr. Carpenter which incorporate more of the parameters experienced during explosive welding. Encouraging results were obtained in welding lead to steel. These results will be reported when more data is obtained.

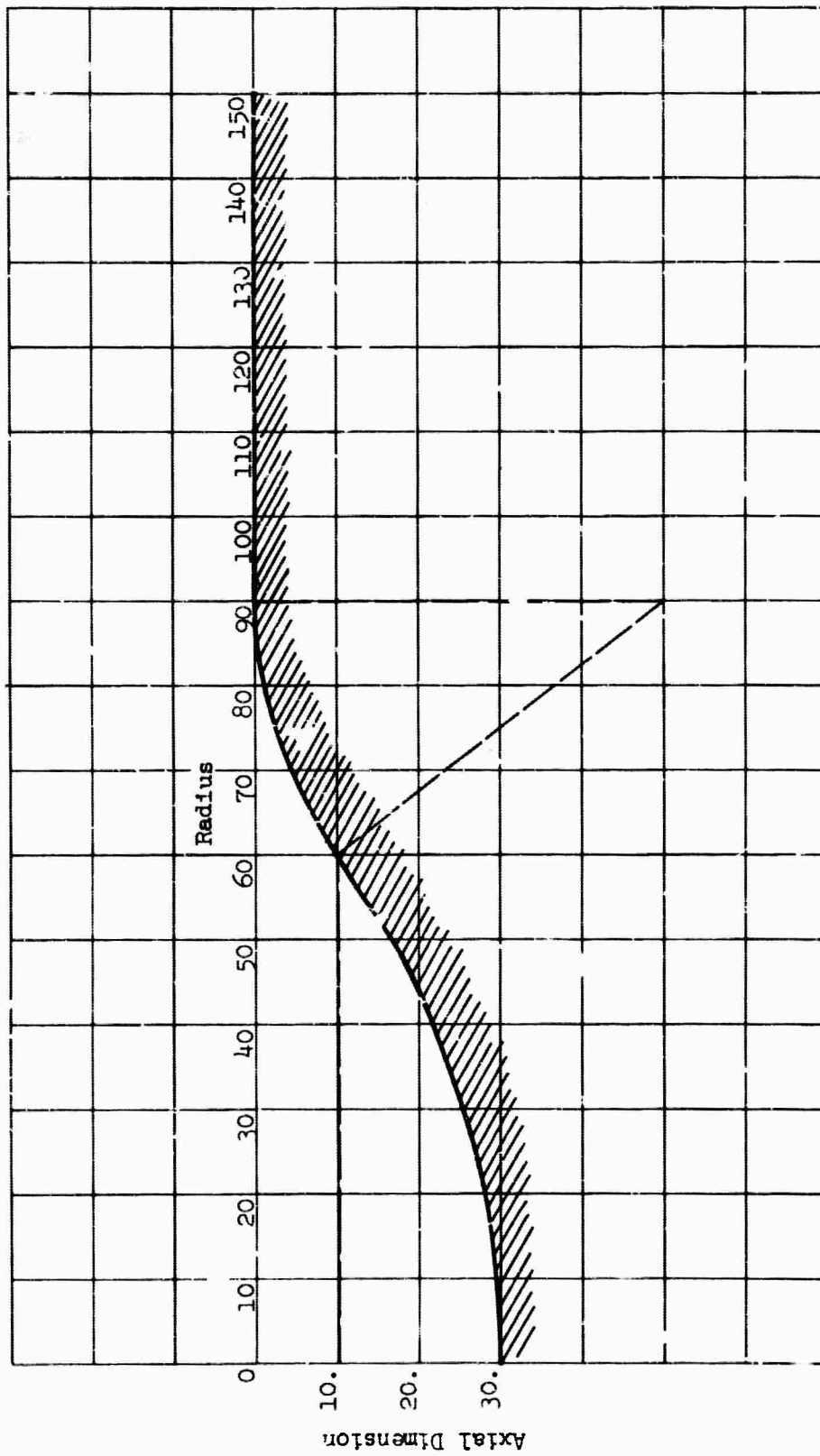


Figure 1. Die Contour for Computer Test Case

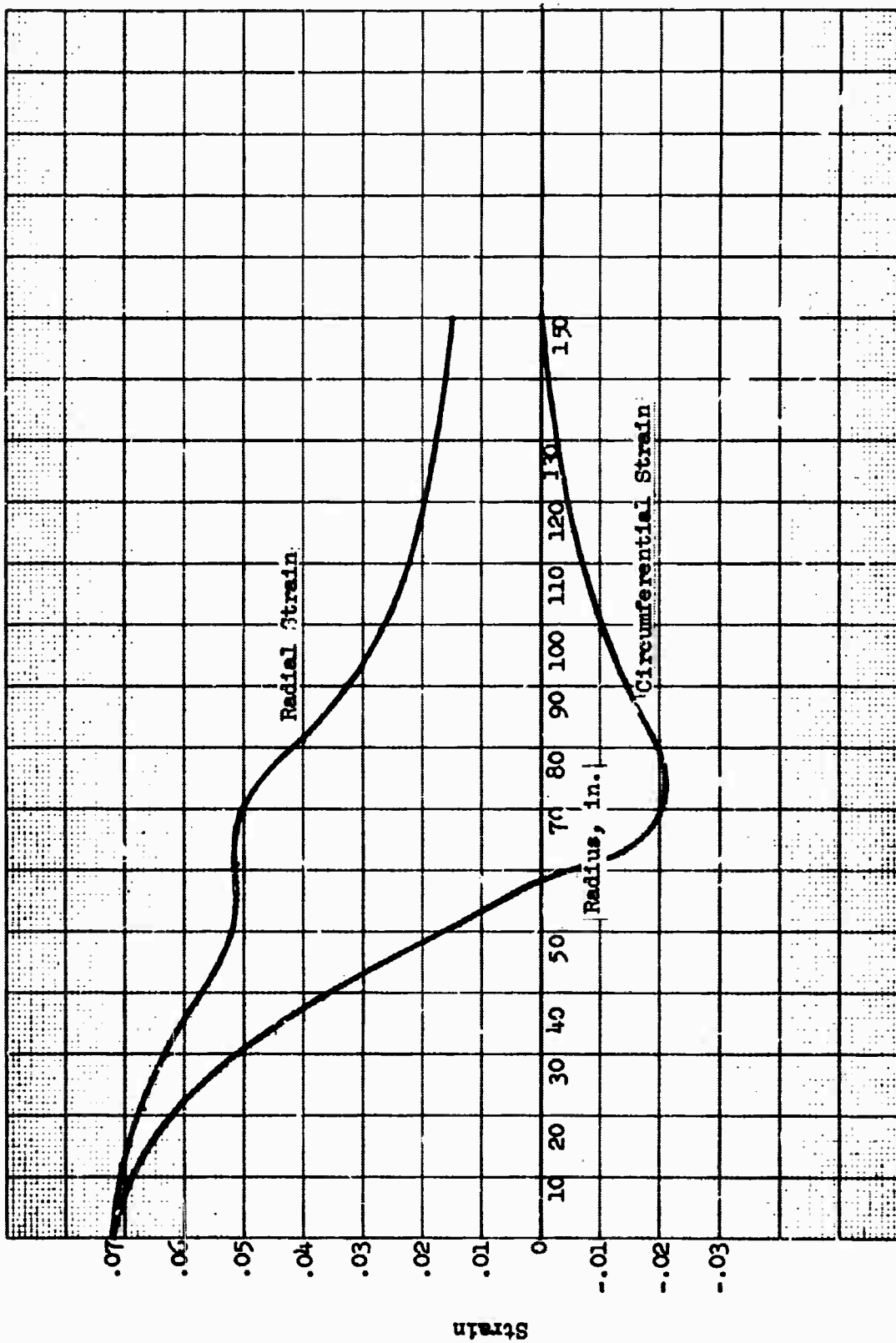


Figure 2. Computed Strains as a Function of Blank Radius

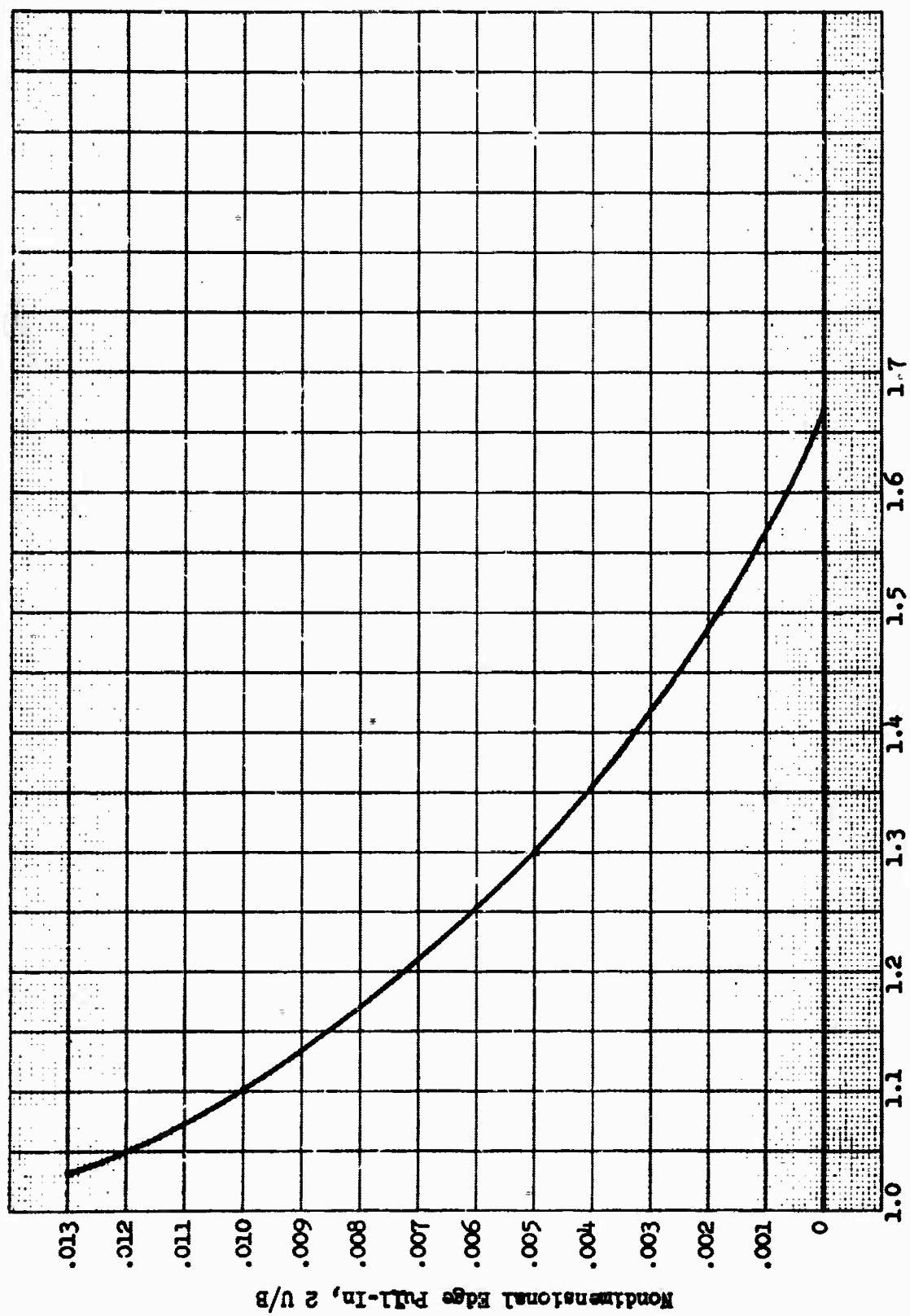


Figure 3. Required Edge Pull-In for Same Strain Distribution in Dome

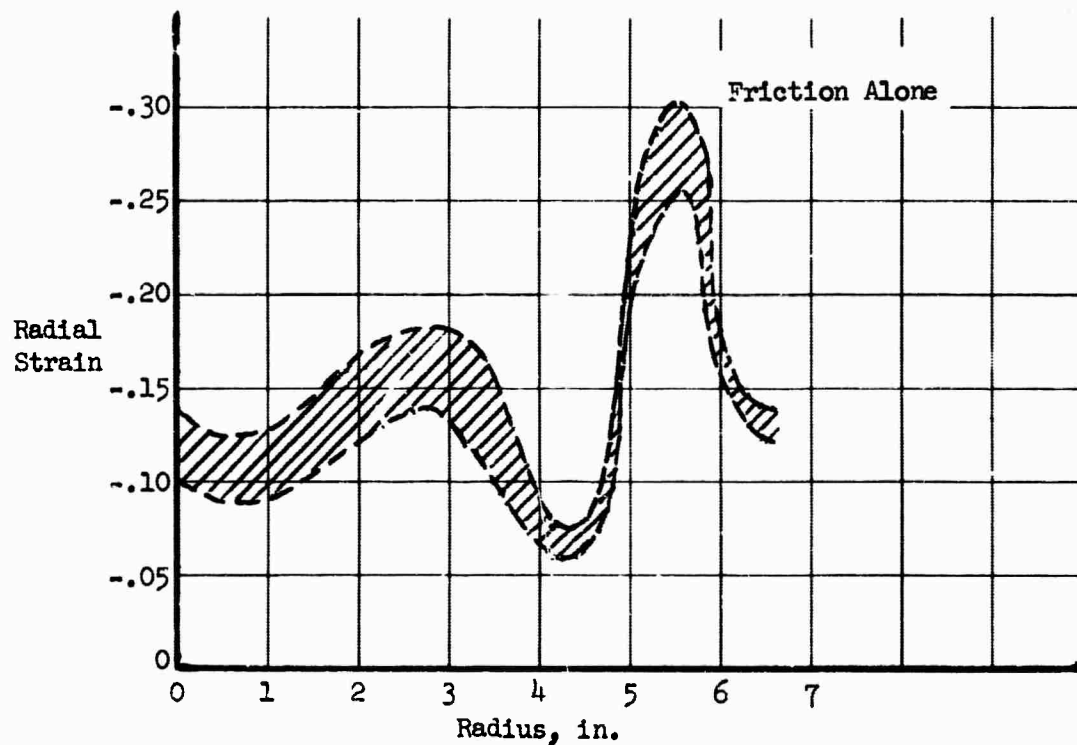
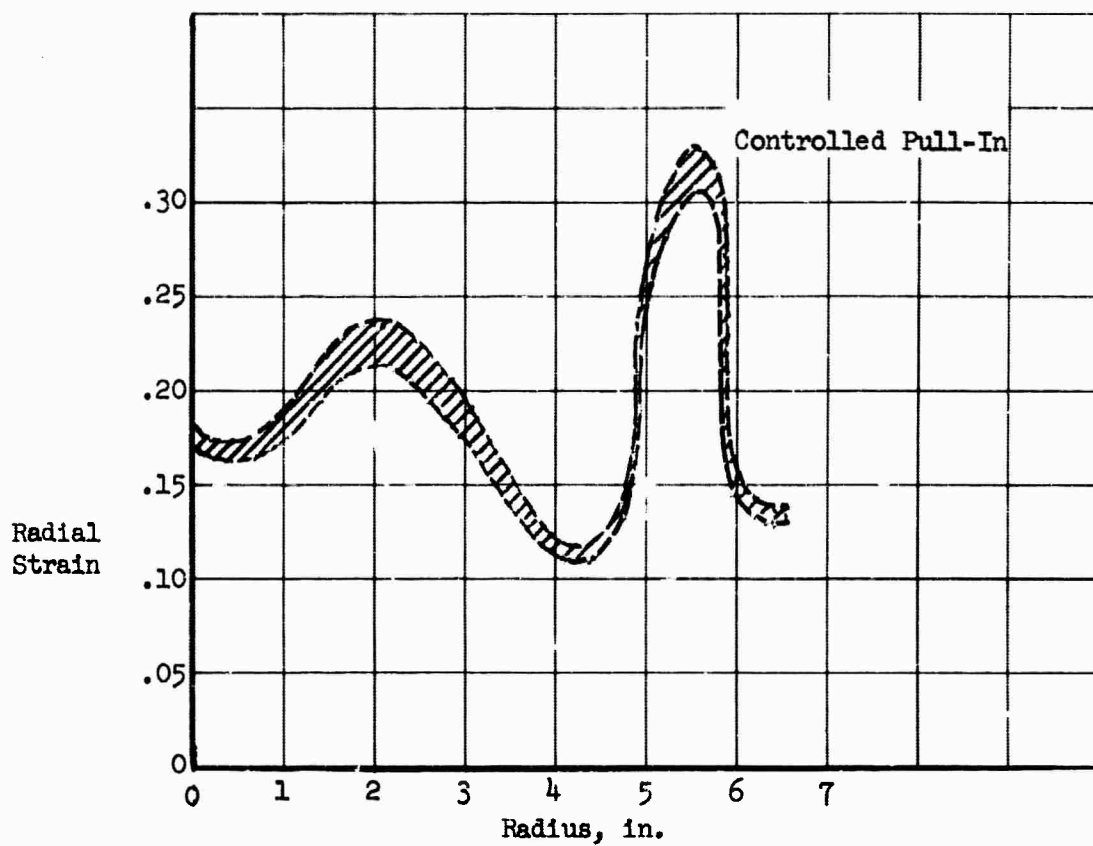


Figure 4. Scatter Band for Radial Strains in Blanks with Controlled Pull-In Compared to Those with Pull-In Controlled by Friction Alone

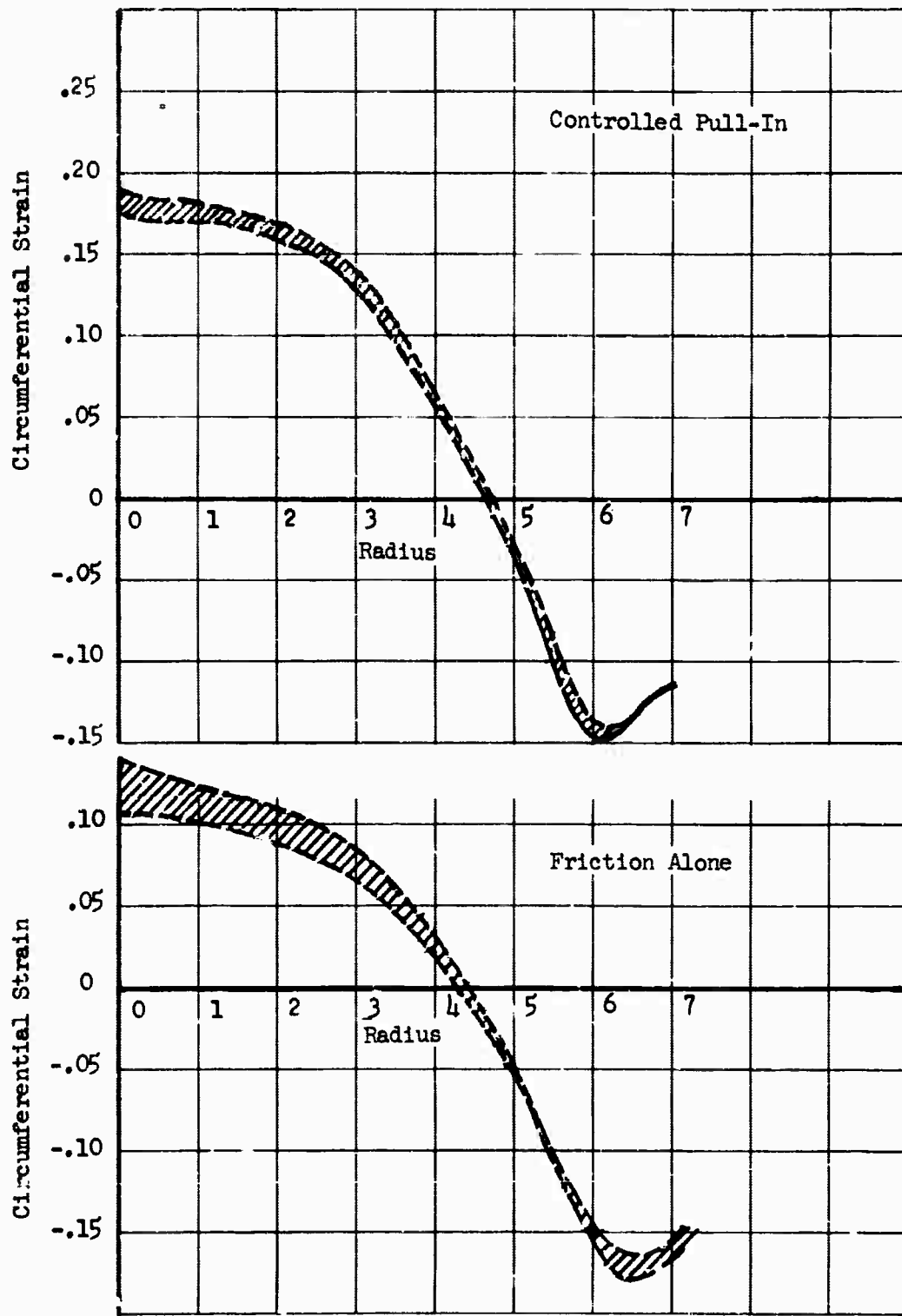


Figure 5. Scatter Band for Circumferential Strain in Blanks with Controlled Pull-In Compared to those with Pull-In Controlled by Friction Alone

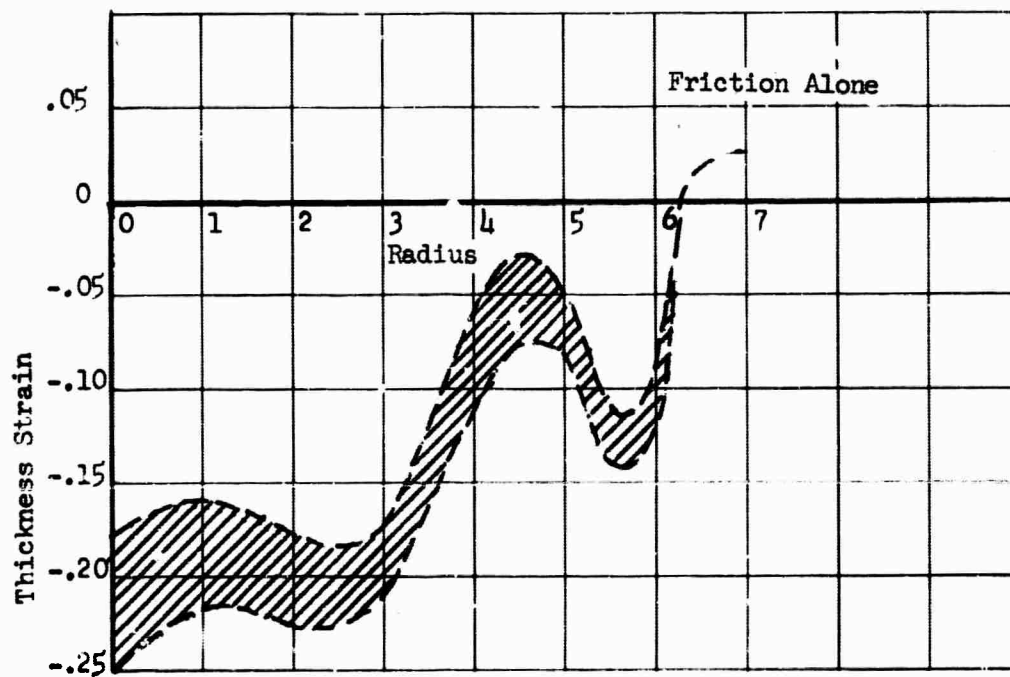
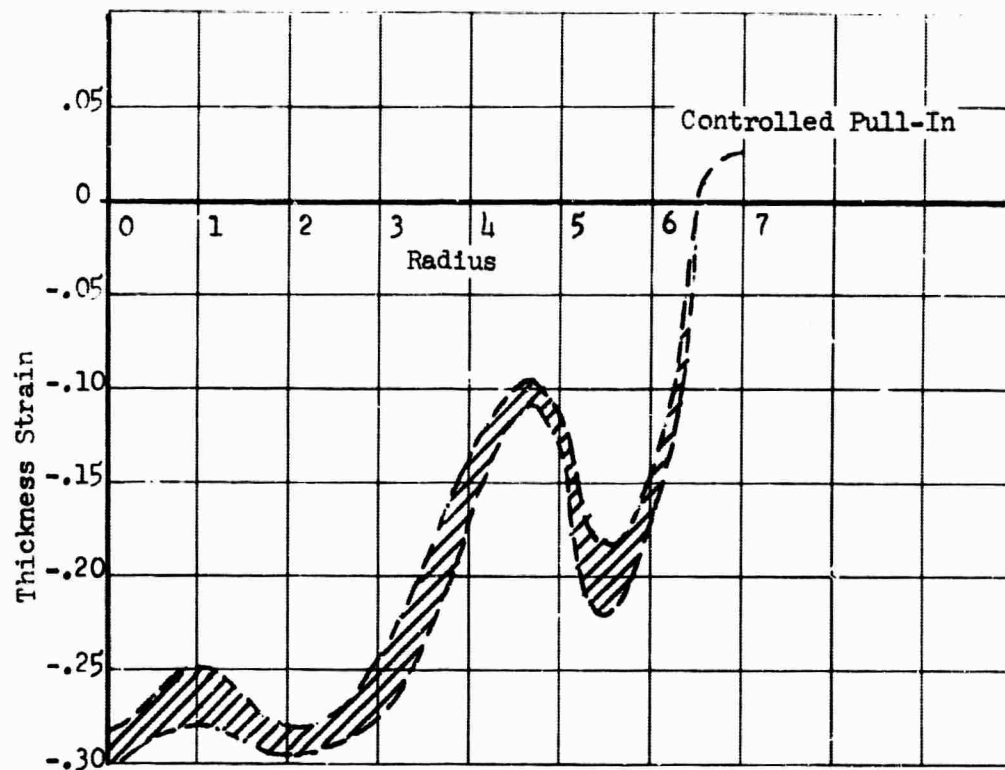


Figure 6. Scatter Band for Thickness Strain in Blanks with Controlled Pull-In Compared to those with Pull-In Controlled by Friction Alone

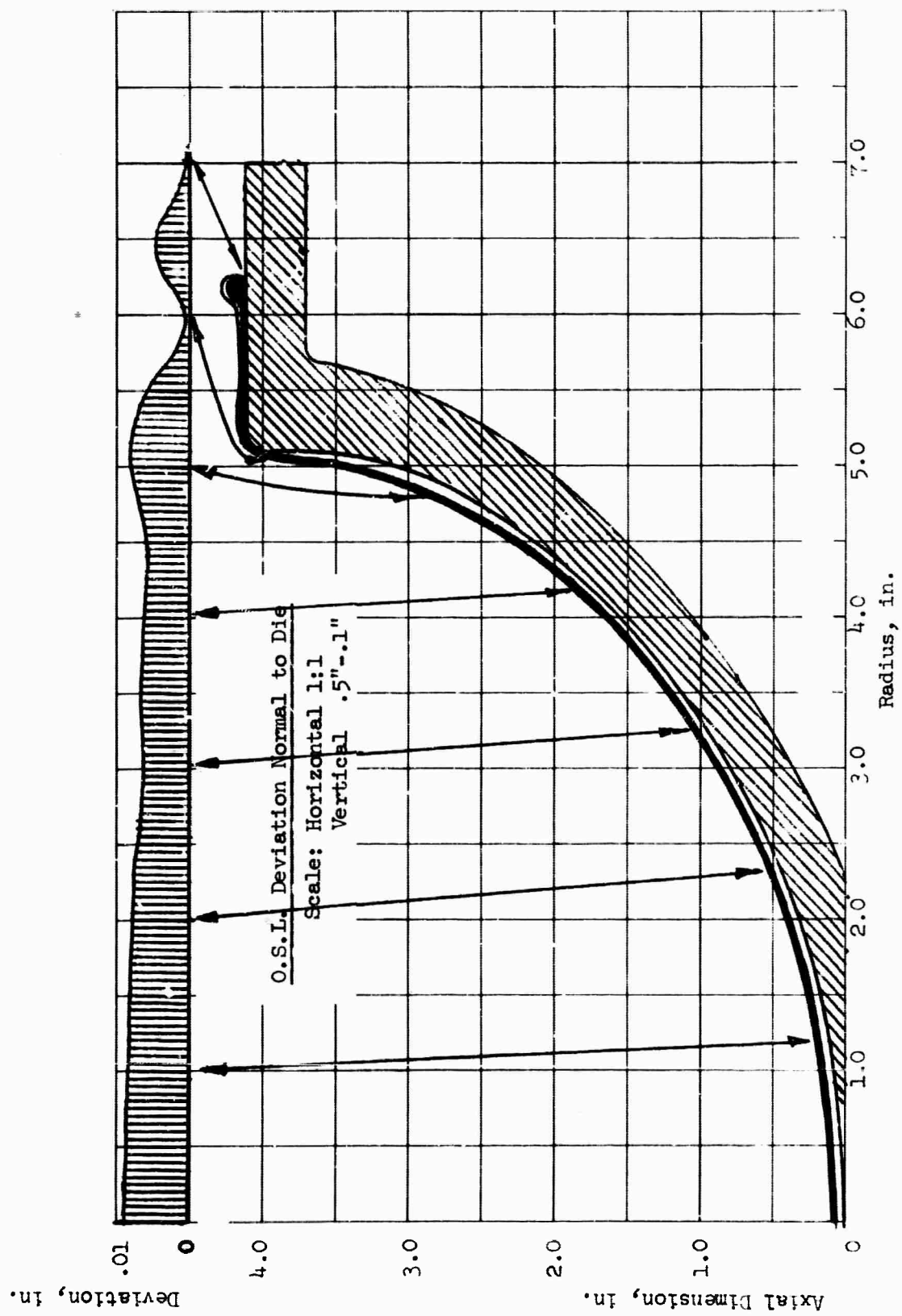


Figure 7. Deviations from Die Contour for Blanks with Controlled Pull-In

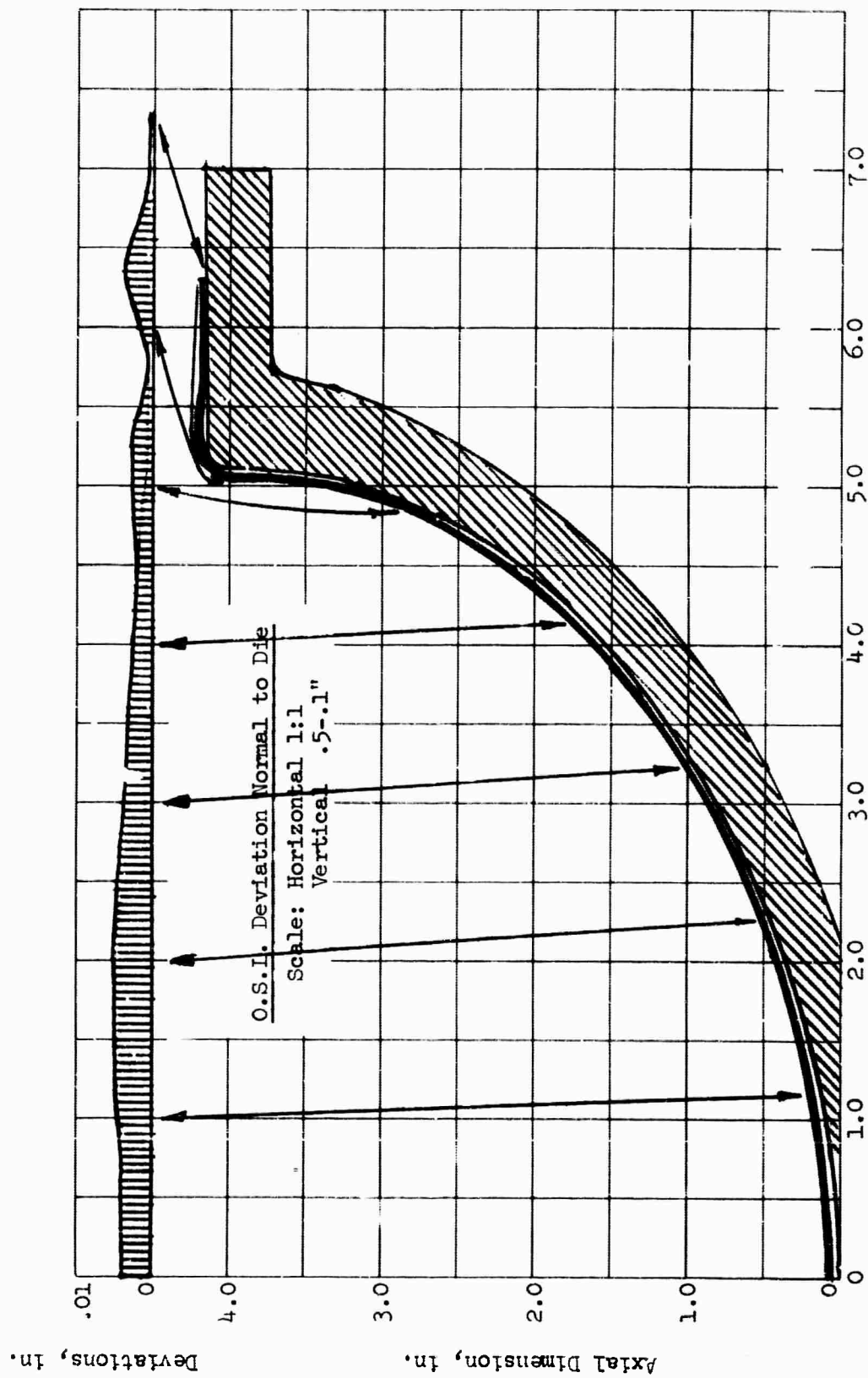


Figure 8. Deviations from Die Contour for Blanks with Pull-In Controlled by Friction

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Blank Pull-In						
Plastic Strain Calculation						
Explosive Forming						
Shock Hardening						
Strain Rate Effect						

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